MODULAR OPTICAL SWITCH FABRIC

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to optical switches, and particularly to modular optical switch fabrics.

2. Technical Background

Over the past several decades, fiber optic technology has transformed the telecommunications industry. A decade ago, network designs included relatively low-speed transceiver electronics at each end of a communications link. Light signals were switched by being converted into electrical signals. The electrical signals were switched using electronic switches, and converted back again into light signals. The bandwidth of electronic switching equipment is in the Gigahertz range. On the other hand, the bandwidth of single mode fiber is in the Terahertz range. As the demand for bandwidth increased, network designers have sought ways to exploit the bandwidth in the 1550nm region. Thus began the development of optically transparent switching fabrics.

In one approach, optical designers have considered using planar optical circuit technology to create space division optical switches. In other approaches, designers have considered using movable MEMS mirrors in planar waveguide arrays to create optical switches. Unfortunately, it is very difficult to create large scale N x N optical switch fabrics using these approaches.

In yet another approach being considered, designers are investigating free-space plane-to-plane optical interconnects, referred to as three-dimensional optical cross-connects (3D OXCs). 3D OXCs have the potential to make large scale N x N (e.g., 4000 port x 4000 port) switching a reality. However, there are several drawbacks to large scale N x N switching fabrics. Once demand exceeds the capacity of the N x N fabric, the entire fabric must be replaced by a larger fabric. Thus, large replacement costs and service interruptions are incurred. Network managers face the same problem

if a portion of the fabric becomes damaged. The entire fabric must be replaced. Finally, designers are having difficulties producing large scale N x N fabrics. The alignment between collimator arrays and beam steering arrays must be fixed over the lifetime of the fabric, and under the operating conditions that the fabric is subject to.

What is needed is a modular optical N x N switching fabric that allows "pay-as-you-grow" upgrades. In other words, a switch fabric is needed that can be expanded by simply adding switching capacity as needed. What is also needed is a modular optical N x N switching fabric that includes modules that can be replaced and repaired without causing interruptions in service. Smaller fabrics are also advantageous in the sense that a module having a unit array size significantly smaller than the aggregate array size can be more easily produced.

SUMMARY OF THE INVENTION

The present invention addresses the needs described above. The present invention provides a modular optical N x N switching fabric that allows "pay-as-you-grow" upgrades. The present invention allows users to expand the switch fabric capacity by simply adding another switch fabric module. The present invention also features a modular optical N x N switching fabric having modules that can be replaced and repaired without causing interruptions in service. The optical modules are advantageous because they include smaller fabrics that are more easily produced than large scale fabrics.

One aspect of the present invention is a modular optical switch fabric that includes an optical chassis. At least one optical module is removably coupled to the optical chassis. The at least one optical module includes a collimator panel and a beam steering panel secured to a frame member. The frame member is configured to position the collimator panel in fixed optical alignment relative to the beam steering panel.

In another aspect, the present invention includes a modular optical switch fabric that includes an optical chassis. A reflective element is attached to the optical chassis. At least one optical module is mechanically coupled to the optical chassis and optically coupled to the mirror. The at least one optical module includes a collimator panel and a beam steering panel secured to a frame member. The frame member is configured to

position the collimator panel in fixed optical alignment relative to the beam steering panel.

In another aspect, the present invention includes a modular optical switch fabric that includes an optical chassis. At least one pair of optical modules are coupled to the optical chassis. A first optical module of the pair of optical modules is optically coupled to a second optical module of the pair of optical modules. Each optical module includes a collimator panel and a beam steering panel secured to a frame member. The frame member is configured to position the collimator panel in fixed optical alignment relative to the beam steering panel.

In another aspect, the present invention includes a modular optical switch fabric that includes an optical chassis having a chassis connector. At least one optical module has an optical module connector mating with the chassis connector such that the at least one optical module is removably coupled to the optical chassis. The at least one optical module includes a collimator panel and a beam steering panel secured to a frame member. The frame member is configured to position the collimator panel in fixed optical alignment relative to the beam steering panel.

In another aspect, the present invention includes a modular optical switch fabric that includes an optical chassis having at least one first chassis connector and at least one second chassis connector. A reflective element is attached to the optical chassis. At least one pair of optical modules includes a first optical module and a second optical module, the first optical module has a first optical module connector mating with the at least one first chassis connector, and the second optical module has a second optical module connector mating with the at least one second chassis connector, such that the first optical module is optically coupled to the second optical module via the reflective element. Each optical module includes a collimator panel and a beam steering panel secured to a frame member. The frame member is configured to position the collimator panel in fixed optical alignment relative to the beam steering panel.

In another aspect, the present invention includes an optical module for use in an optical switch fabric. The optical module includes a frame member, a collimator panel

secured to the frame member, and a beam steering panel secured to a frame member. The collimator panel is in fixed optical alignment relative to the beam steering panel.

In another aspect, the present invention includes a method for directing a light signal in an optical switch fabric. The optical switch fabric includes an optical chassis. The method includes the step of providing at least one optical module removably coupled to the optical chassis. The at least one optical module includes a collimator element and a beam steering element each secured to a frame member. The frame member is configured to position the collimator element in fixed optical alignment relative to the beam steering element. The light signal is input into the optical module via the collimator element, whereby the light signal is automatically directed onto the beam steering element by virtue of the fixed optical alignment provided by the frame.

In another aspect, the present invention includes a method for directing a light signal in an optical switch fabric. The optical switch fabric includes an optical chassis and a reflective element mounted on the optical chassis. The method includes providing at least one pair of optical modules removably coupled to the optical chassis. A first optical module of the pair of optical modules is optically coupled to a second optical module of the pair of optical modules via the reflective element. The first optical module includes a first collimator element and a first beam steering element secured to a first frame member. The first frame member is configured to position the collimator element in fixed optical alignment relative to the first beam steering element. The second optical module includes a second collimator element and a second beam steering element secured to a second frame member. The second frame member is configured to position the collimator element in fixed optical alignment relative to the beam steering element. The light signal is directed into the first optical module via the first collimator element, whereby the light signal is automatically directed onto the first beam steering element by virtue of the fixed optical alignment provided by the first frame. The light signal is steered from the first beam steering element to the second beam steering element via the reflective element, whereby the light signal is automatically directed into the second collimator element by virtue of the fixed optical alignment provided by the second frame.

In another aspect, the present invention includes a method for maintaining an optical switch fabric being used to direct signal traffic. The signal traffic includes light

signals being directed from input fibers to output fibers. The method includes providing an optical chassis having a plurality of plug-in slots. The plug-in slots include at least one repair slot. A plurality of first optical modules are inserted into the plug-in slots of the optical chassis. The at least one repair slot is unused. Each optical module includes a collimator element and a beam steering element each secured to a frame member. The frame member is configured to position the collimator element in fixed optical alignment relative to the beam steering element. A maintenance condition is detected. At least one second optical module is inserted into the at least one repair slot in response to the maintenance condition; whereby the signal traffic is not interrupted.

Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the invention as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

It is to be understood that both the foregoing general description and the following detailed description are merely exemplary of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate various embodiments of the invention, and together with the description serve to explain the principles and operation of the invention.

Brief Description of the Drawings

Figure 1 is a diagrammatic depiction of a folded-Z modular optical switch fabric in accordance with a first embodiment of the present invention;

Figure 2 is a detail view of an optical module used in the switch fabric shown in Figure 1;

Figure 3 is a detail view of a gimbaled pixel employed in the optical modules of the present invention;

Figure 4 is a detail view of a pixel mirror element employed in the gimbaled pixel shown in Figure 3;

Figure 5 is a diagrammatic depiction of a fully populated modular optical switch fabric in accordance with a first embodiment of the present invention;

Figure 6 and Figure 7 are a diagrammatic depictions of the folded-Z modular optical switch fabric with repair slots; and

Figure 8 is a diagrammatic depiction of a cylindrical modular optical switch fabric in accordance with a second embodiment of the present invention;

DETAILED DESCRIPTION

Reference will now be made in detail to the present exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. An exemplary embodiment of the modular optical switch fabric of the present invention is shown in Figure 1, and is designated generally throughout by reference numeral 10.

In accordance with the invention, the present invention for a modular optical switch fabric includes an optical chassis. At least one optical module is removably coupled to the optical chassis. The at least one optical module includes a collimator panel and a beam steering panel secured to a frame member. The frame member is configured to position the collimator panel in fixed optical alignment relative to the beam steering panel. The present invention provides a modular optical N x N switching fabric that allows "pay-as-you-grow" upgrades. The present invention allows users to expand the switch fabric capacity by simply adding another module. The present invention also features a modular optical N x N switching fabric having modules that can be replaced and repaired without causing interruptions in service. The optical modules are advantageous because they include smaller fabrics that are more easily produced than large scale fabrics.

As embodied herein, and depicted in Figure 1, a diagrammatic depiction of a folded-Z modular optical switch fabric 10 in accordance with a first embodiment of the present invention is disclosed. Fabric 10 includes optical chassis 20. Optical chassis 20 includes plug-in slots 22 for in-service optical modules 100. As shown in Figure 1,

expansion optical module 50 is being inserted into vacant slot 24 and optical module 60 is being inserted into vacant slot 26 to expand the capacity of switch fabric 10. Reflector 30 is connected to optical chassis 20 in fixed alignment with all in-service optical modules 50, 60 and 100. Optical modules 50, 60 and 100 include male electrical connectors 112 which mate to female electrical connector 220 disposed in slots 22, 24, and 26. Female electrical connector 220 is coupled to control bus 42. Control bus 42 is connected to control system 40. Control system 40 is configured to supply individual control signals to each pixel in switch fabric 10.

It will be apparent to those of ordinary skill in the pertinent art that modifications and variations can be made to control system 40 of the present invention depending on the overall capacity of switch fabric 10. For example, control system 40 may include a 32-bit microprocessor, a RISC processor, or an application specific integrated chip (ASIC). The ASIC may be implemented using a programmable logic array (PLA) device, or by a field programmable gate array (FPGA) device. In another embodiment, control system 40 is implemented using computing resources disposed in the network.

As embodied herein and depicted in Figure 2, a detail view of optical module 100 used in switch fabric 10 is disclosed. Optical module 100 includes frame 102, which accommodates collimator panel 104, and beam steering panel 106 therebetween. In the embodiment shown in Figure 2, collimator panel 104 terminates 324 fibers (9 rows x 36 fibers) in 324 collimating lenses. Thus, beam steering panel 106 includes 324 steerable pixels corresponding to each fiber collimator. Frame 102 is configured to align each fiber collimator with one pixel. Mechanical frame 102 ensures that alignment between each pixel and its corresponding collimator is fixed, and does not drift over time and operating conditions. This is a critical alignment and must be maintained for the proper operation of the switch fabric 10.

As embodied herein and depicted in Figure 3, a detail view of gimbaled pixel assembly 108 employed in accordance with the present invention is disclosed. Assembly 108 includes reflective pixel element 1080. Pixel 1080 is coupled to frame member 1082 via beam 1085 and beam 1086. Beam 1085 and beam 1086 allow pixel

element 1086 to rotate around the y-axis. Frame member 1082 is coupled to substrate 1088 via beam 1083 and beam 1084. Beam 1083 and beam 1084 allow frame member 1082 to rotate about the x-axis. Thus, pixel element is steerable with 2-degrees of freedom. As shown in Figure 3, pixel assembly 108 is suspended over trench 1100. An electrostatic actuator assembly (not shown) is disposed under pixel assembly 108 in trench 1100. The electrostatic actuator assembly is coupled to control system 40 via control bus 42, and connectors 220/112. The actuator assembly includes an electrode disposed under each beam (1083, 1084, 1085, and 1086). To cause a rotation around beam 1083 and beam 1084, the electrodes under beam 1085 and 1086 are actuated by applying an actuation voltage. To cause a rotation around beam 1085 and beam 1086, the electrodes under beam 1083 and beam 1084 are actuated by applying an actuation voltage. The beams twist when they are rotated and become springs that supply a balancing force to the applied electro-static forces. The beams also supply a return force when the applied voltage is reduced.

As embodied herein and depicted herein and depicted in Figure 4, a detail view of pixel element 100 is disclosed. Pixel element 1080 includes reflective surface 1092 disposed on substrate 1092. It will be apparent to those of ordinary skill in the pertinent art that modifications and variations can be made to pixel element 1080 of the present invention depending on the beam size of incident light signals. For example, the side dimensions of pixel element 1080 may range between 200μm to 1mm. The width of pixel element 1080 is usually below 10μm, and typically about 5μm. One of ordinary skill in the art will also recognize that pixel element 1080 can be formed using a number of photolithographic techniques, such as MEMS micro-machining. In one embodiment, substrate 1090 is formed using a silicon material. Reflective layer 1092 is formed by depositing a layer of gold over substrate 1090.

As embodied herein and depicted in Figure 5, a diagrammatic depiction of a fully populated modular optical switch fabric in accordance with a first embodiment of the present invention is disclosed. In the example shown in Figure 5, optical modules 100 function as input optical modules and optical modules 100' operate as output optical modules. Of course, control system 40 can accommodate optical modules 100 having both input collimators and output collimators. One of ordinary skill in the art

will recognize that it is merely a matter of reconfiguring the control system software. The switch fabric 10 shown in Figure 5 in a 1296 port switch fabric (324 x 4).

Figure 6 and Figure 7 are a variations of the folded-Z modular optical switch fabric shown in Figure 1 and Figure 5. In the example depicted in Figure 6, switch fabric 10 includes repair slots 24. In this example, optical module 110 is subject to a maintenance action. A maintenance action can be necessitated by a failed module 100, or it can also be necessitated by a scheduled maintenance event. As shown in Figure 7, traffic originating or terminating in module 110 has been re-routed by control system 40 in response to the maintenance action. Subsequently, new optical module 112 is inserted into repair slot 24. Control system employs optical module 112 to propagate traffic within switch fabric 10.

As embodied herein and depicted in Figure 8, a diagrammatic depiction of a cylindrical modular optical switch fabric 10 in accordance with a second embodiment of the present invention is disclosed. Cylindrical switch fabric 10 includes optical chassis 220. Chassis 220 includes a central cylindrical core 222. Core 222 includes reflector 30 disposed on base 230 of core 222. Typically, reflector 30 is a convex mirror that facilitates connections between any input and any output port. Chassis 220 also includes a ring portion 224 which is disposed around core portion 222. Ring portion 224 includes annulus 226 which surrounds base 230. The collimators (212) in switch fabric 10 are disposed within annulus 226. The beam steering pixels (208) are disposed within annulus 228. In this second embodiment, optical module 200 is shaped like a prism. The lateral surface area of the cylinder shaped fabric 10 is formed by arcuate frame member 202A. Arcuate frame member 202B is configured to mate with central cylindrical core 222. Collimator panel 204 and beam steering pixel panel 206 are disposed between frame member 202A and frame member 202B. The benefit of the cylindrical shape is that it allows the removal of any optical module 200 from the front, without disrupting traffic in any of the other modules 200.

It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the

modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.